Development and Applications of Special Concretes
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Lecture 09
Admixtures in Concrete

Welcome back to our module on development and applications of special concretes. This is another lecture and today we will be talking about admixtures in concrete.

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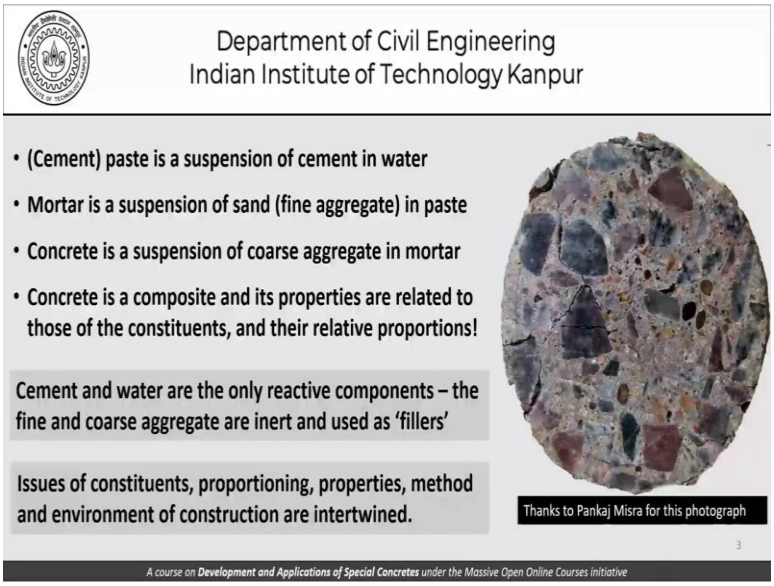

This is a familiar slide and I have thought that I will not repeat it but today I thought in view of the discussion and its relevance it is better to revisit this once again. Cement paste is a suspension of cement in water. Now the definition of cement is what is likely to change as a result of the discussion that we have today mortar is a suspension of sand, which is fine aggregate in paste concrete is a suspension of coarse aggregate and mortar.

Concrete is a composite and its properties are related to those of its constituents and their relative proportions. And the moment we add anything other than cement, water, sand and gravel which we are calling coarse aggregate, this is the fine aggregate, the properties are likely to change because the constituents have changed. So that is what we are going to do today and cement and water are the only reactive components and the rest of it is fillers.

This aspect also is likely to undergo a little bit of modification as, we shall see later on in this lecture and the issues of constitution proportioning properties and methods and environment of construction are all intertwined. As we will now begin to see as we enter different aspects of special concretes.

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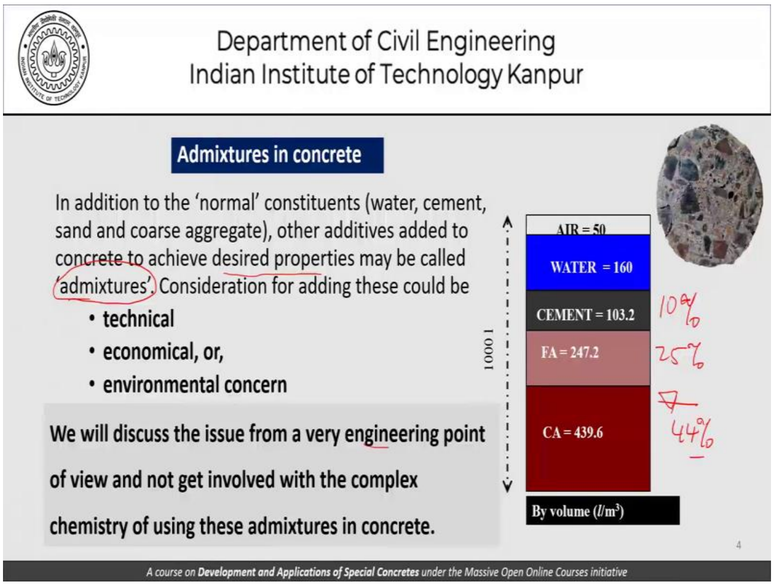

Having said that, let us start our discussion in admixtures in concrete. This is what has been taken from the example that we have already solved this is by volume this is our 1000 litre pitcher, 50 litres of air 160 litres of water, 103.2 litres of cement, that is about 10.3% or 10%, let us say 247 or maybe say 25% of fine aggregate and about 44% of coarse aggregate. This is whatever normal distribution of materials in normal concrete is.

That is a concrete which does not have any admixtures. Now in addition to these normal constituents, that is water cement sand and coarse aggregate other additives are at times added to concrete to achieve desired properties and these are what are called admixtures. Consideration or the reasons for adding these could be technical, economical or also environmental concern. So, we will try to look at some of these issues as we go along today will just be an overview.

And possibly the treatment of special concretes which will start one of these days. We will understand or we will come to know these issues better. Having said that, we will discuss this issue of admixture addition from a very engineering viewpoint. And not get involved with the complex chemistry of using these admixtures in concrete. Obviously if we add admixtures to concrete certain changes happen.

Now those changes as an engineer we should be aware of them. We should know the reasons for that but it is not all that important for us to know the reasons beyond a certain point. So long as we are clear about the engineering applications, how to keep them under control and what are the implications of that? What are the things that we should watch out for, when we add admixtures, that is the viewpoint that is the kind of standpoint that I will take when, I discuss this subject.

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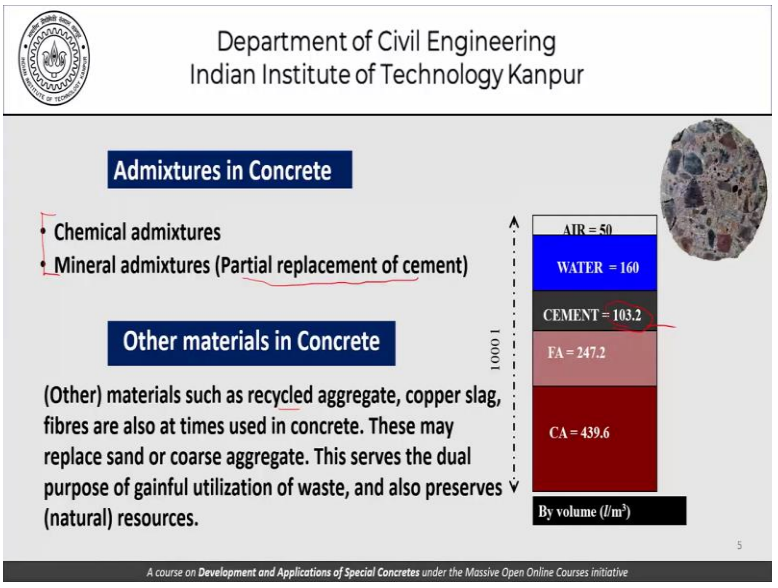

Now there are two kinds of admixtures in concrete: chemical admixtures and mineral admixtures. Now mineral admixtures are used in partial replacement of cement. So, I am showing you this slide all the time because these 103.2 litres is what is likely to change. There are instances when we will use other materials in concrete and we actually use other materials in concrete such as recycled aggregate, copper slag, fibres and so on.

But these are not chemical or mineral admixtures and I would not like to call them admixtures. We will treat this aspect of addition of additional material compared to the traditional or the normal water, cement, sand and gravel combination in a slightly different way. So as far as admixtures are concerned, we will confine ourselves to chemical admixtures and mineral admixtures.

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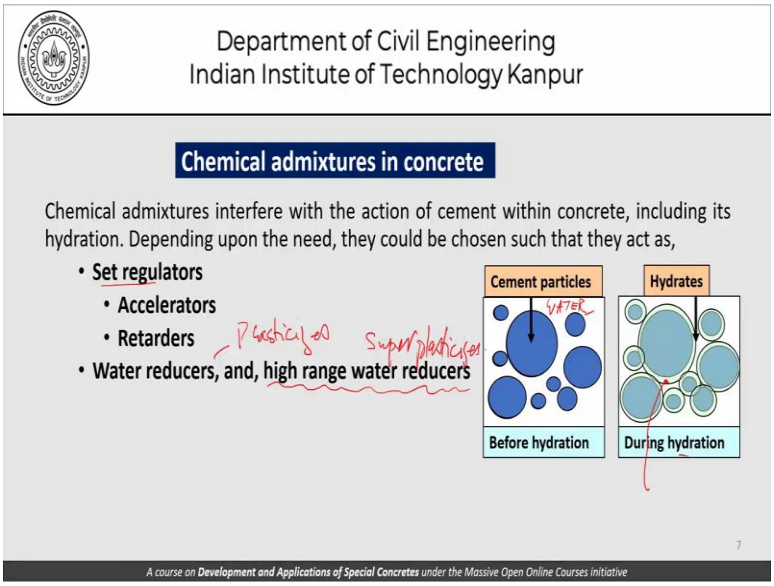

Now that's what I said we will confine our attention to chemical admixtures and mineral admixtures and starting with chemical admixtures. Let us try to understand them a little better. Chemical admixtures interfere with the action of cement within concrete including its hydration. And depending upon the need they can be chosen in several ways. This is a picture which we have seen, before cement particles here surrounded by water here this is water.

And as soon as water and cement particles come in contact with each other hydration starts and this hydration means that these hydrates or these hydration products begin to form around the cement particles of course I have shown spherical cement particles separated from each other and so on. That again is a myth and it is a model we will try to understand this a little differently from now on.

Coming back to how these chemical admixtures can act and how we can choose them. One way of doing it is set regulation, that is we can determine or we can engineer the setting rate that is we can accelerate the setting process and if those admixtures are added which accelerate the setting process. Those are called accelerators and opposite to that there are retarders which retard the setting action.

Apart from these set regulators there are water reducers and at times they are called high range water reducers depending on the power involved depending on the amount of reduction of water that they can get. So, there are water reducers as a generic name and then there are high range water reducers which are also sometimes called super plasticizers. And the water reducers in general are called plasticizers.

We will see how they work and I leave it to you for an assignment to find out about the chemistry of these different chemical admixtures. Then there are air entrainers and of course there are other chemical admixtures such as corrosion inhibitors. So, these are the kind of general properties that we can engineer with the use of chemical admixtures as far as concrete is concerned.

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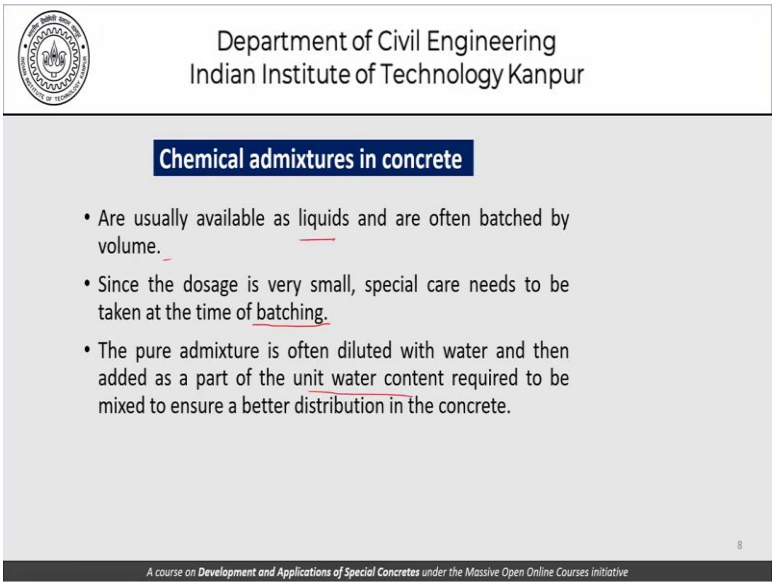

Now these chemical admixtures are usually available as liquids and are often patched by volume. Once they are available as liquids one does not necessarily have to batch them by weight. Volume is a good enough way of doing it and that is how it is often done. Since the dosage is very small special care needs to be taken at the time of batching to ensure that they are uniformly and homogeneously distributed throughout the concrete mix.

The pure admixture is often diluted with water and then added as a part of the unit water content required to be mixed to ensure a better distribution in the concrete. We will see this part a little bit in the example sometime later on.

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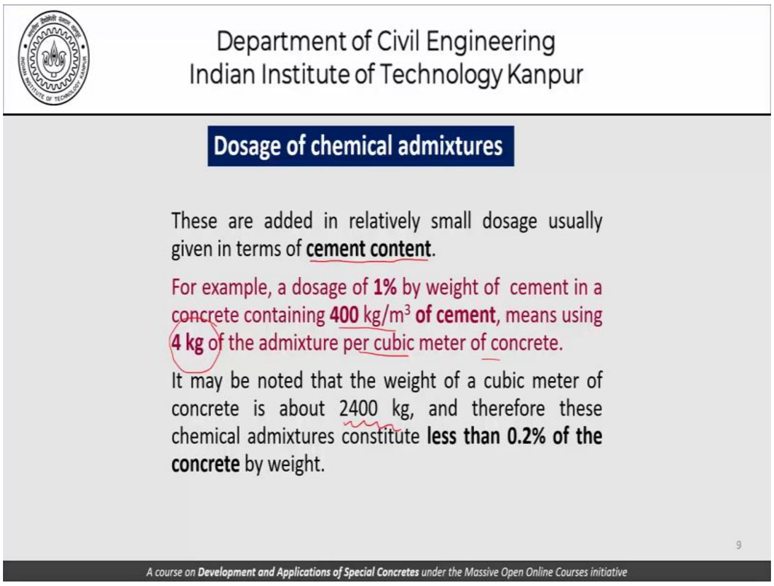

These chemical admixtures because they kind of act on the hydration process involved their dosage is often given in terms of the cement content that is it is given as 1% or half a percent or 1 and a half percent of the cement content in the mix. For example, 1% dosage by weight of cement in concrete containing 400 kgs per cubic meter of cement means that 4 kgs of that admixture per cubic meter of concrete should be added.

It should be noted that the weight of the cubic meter of concrete is about 2400 kgs and therefore if you are talking of 1% of addition of a chemical admixture that is a really small value as far as the weight of concrete is concerned or as far as the effect on the weight of concrete is concerned.

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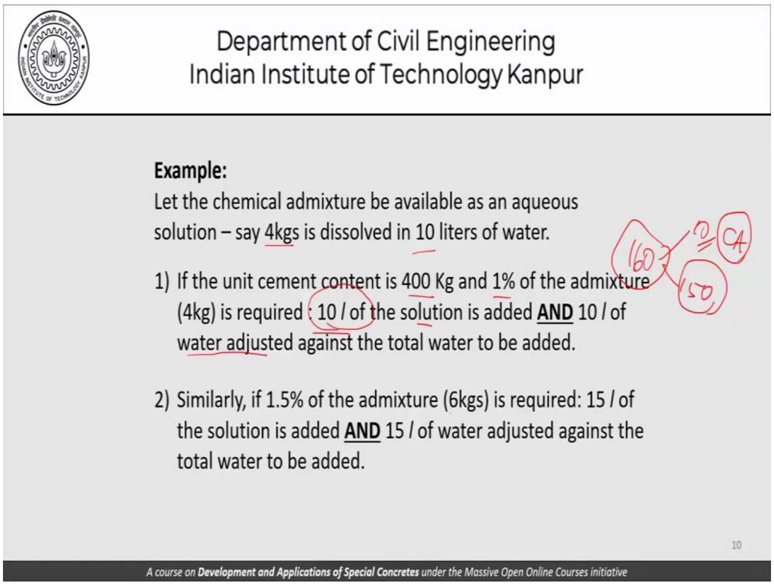

As far as the addition is concerned what we try to do often is to make an aqueous solution say 4 kgs is dissolved in say 10 litres of water and then if the unit content of cement is 400 kgs and 1% of that mixture needs to be added that means 4 kgs is needed to be added what we will do is we will use 10 litres of this solution into the concrete and adjust the total water content accordingly.

That means if the unit water content was 160, we will take 10 out of it and add 150 as water and 10 we have already taken out and added as a chemical admixture or added with the chemical admixture. So that is how we kind of do this small arithmetic involved. If it was 1.5%, we need to add 6 kgs of the admixture which means that we will need to add 15 litres of such a solution.

And then of course this 160 if we take it this will have to be adjusted to 145. So, this 145 kgs of water will be added separately and the 15 kgs of solution with the chemical admixture will be added separately. There is no real reason for it to be separate; you can have as much water as you want and as much chemical admixture as you want in one place or the other. So long as you understand that finally in the mix, we need to add 4 kgs or 6 kgs or whatever it is required that amount of chemical admixture gets added to it, is uniformly distributed that is pretty much all right.

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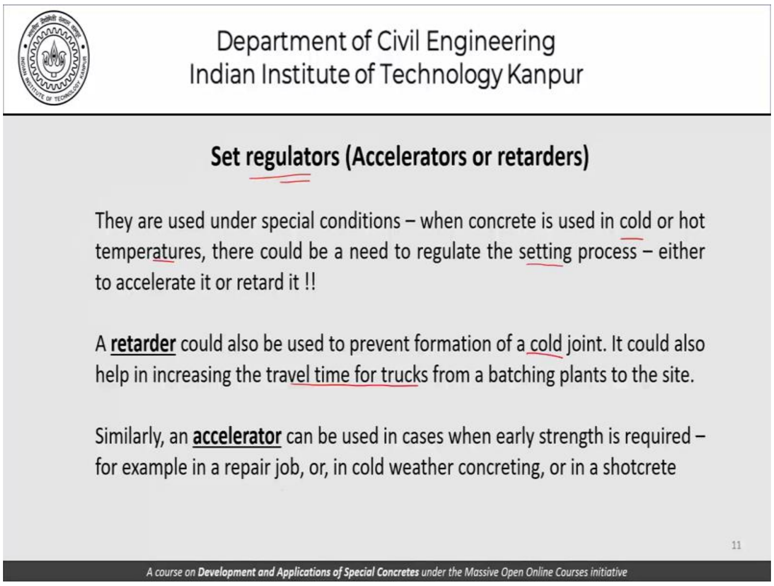

Now then we come to set regulators. Now let us start our discussion on set regulators which was the first type of chemical admixtures that we talked about. These are used under special conditions and that is what is gradually taking us to our main theme of this module or this set of course or this set of lectures special concretes. When concrete is used in very cold or very hot temperatures there could be a need to regulate the setting process either accelerate it or retarders.

Retarders could also be used to prevent the formation of a cold joint. It could help in increasing the travel time for trucks already mixed concrete. The transit mixers from a batching plant to the site on the other hand accelerators can be used in cases when early strength is required. For example, in a repair job or cold weather concreting or an application like a short creed where once placed we want the concrete to be hardening or gaining strength faster than normal.

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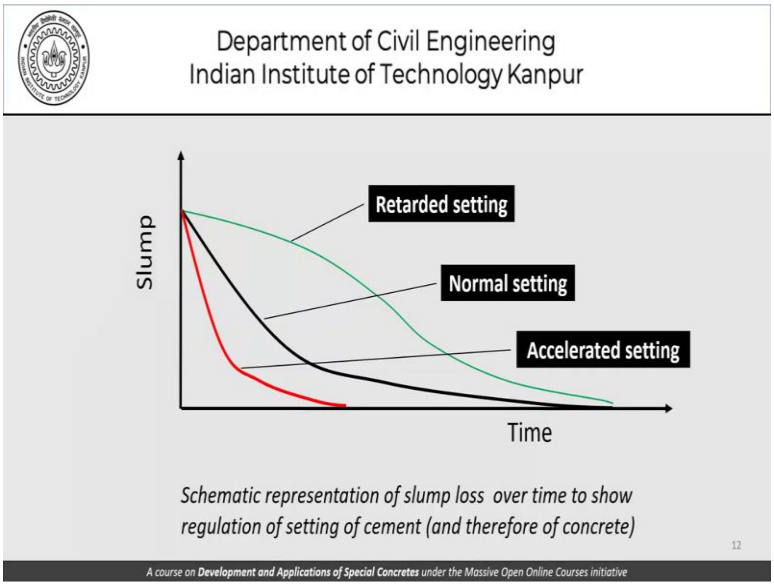

Having said that this is what is a schematic representation of what these set regulators mean if this is how our normal setting process happens and the slump which started from here it starts going to zero. In fact, this long tail possibly does not exist most of the time and the slump pretty much goes to zero at a certain rate or at a certain rate. Now compared to this if we use an accelerator, we will get something like this or if we use a retarder, we get something like this.

So, the slump at a given time can be this or this or this depending on whether it is normal setting, accelerated setting or a retarded setting and that is pretty obvious except that once we are using these accelerators or retarders we have to specify how much of a retardation or how much of an acceleration do we need. So, it is not only the initial slump that needs to be specified but we also need to specify the slump at let us say 3 hours or 4 hours or 15 minutes.

So once the specification is known we will know whether the concrete meets our specification or not because this is something which we have to have at the back of our mind this is the principle. But as an engineer when I am using these kinds of admixtures, what do we want of concrete at a given point in time? Keep that in mind when we are using retarders or accelerators.

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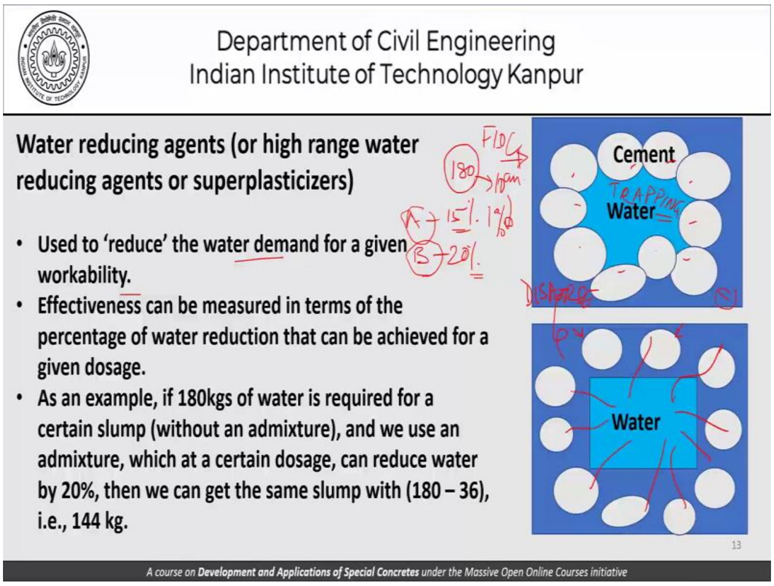

Now coming to the next class of chemical admixtures, the water reducing agents or plasticizers or super plasticizers before we get into this discussion let me explain to you this schematic representation of a flock of cement. Now what is a flock of cement is these cement particles sticking to each other and trapping some water inside. Now we have already seen that the water that is added to the concrete is in excess of the water required for the hydration of cement.

And that additional water is really required to impart the right kind of or the desired amount of workability to concrete if this water gets trapped inside these cement particles that water is no longer available for workability and that is a bad idea. So, what we really try to do through these water reducers is to somehow disperse these cement particles like this and then this water is free all over the place to actually provide workability and be used for the purpose that it is meant for.

Further, more cement area becomes available for hydration once we are using these plasticizers or super plasticizers compared to this situation. So that is the very simplified model that one can use and there is a very simple experiment that you can take in a measuring cylinder with about 100 grams of cement and one litre of water. Let it just stand, shake it up and let it stand you will find that cement will form flocks and very quickly settle down.

Add a little bit of plasticizer to that solution and then see that it takes a long time for cement to settle down and water to become clear. So that is a very simple experiment which will tell you how these plasticizers tend to disperse the flocculated cement particles and release this water and therefore we have plasticizing action and so on as we shall see. Now, these plasticizers are used to reduce the water demand for a given workability or for a given slump level.

The effectiveness of these can be measured in terms of the percentage of water reduction that can be achieved for a given dosage. That means if there is an admixture A which says 15% water can be reduced and an admixture B says 20% of water can be reduced that is if my original water content was 180 kgs and my slump was 10 centimetres or 100 millimetres. If we can get the same slump with 1% of A with 15% reduced water and in this case with 20% reduced water then B is more effective than A.

As an example, if 180 kgs of water is required for a certain slump without an admixture and we use an admixture which at a certain dosage can reduce water by say 20% then we get the same slump at 144 kgs i.e., 136-36, 36 coming from 20% of 180. So that is how we measure the efficiency or we try to understand how much of a super plasticizer or how much of a plasticizer has to be used.

In fact, in the olden days 20 reductions was a lot of reduction and the developments have really been in the area of making more and more effective plasticizers that is being able to achieve more and more reduction in the water content.

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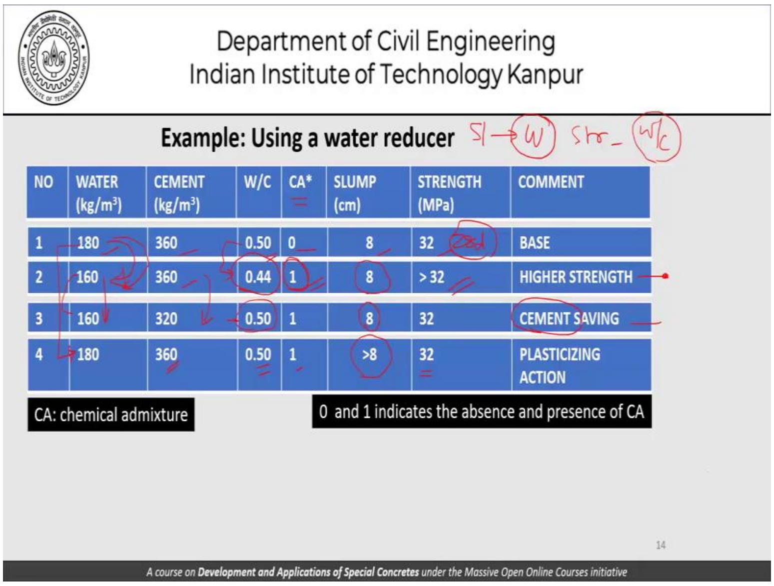

There are different dimensions to using a water reducer. It is not only plasticizing and that is what I want to show in this slide. Suppose I have a base mix which has 180 kgs of water and 360 kgs of cement which means that I am using a water cement ratio of 50%. And the CA here does not refer to coarse aggregates, it refers to chemical admixtures and 0 and 1 indicates the absence and presence of a chemical admixture.

So, this is my base mix without any chemical admixture and suppose we are getting 8 centimetres slump and 32 MPa strength at 28 days or whatever those numbers are. Now if I use a chemical admixture then one way of doing it is that I do not change my cement content I still use the same cement content. But if I am happy with a slump of 8 centimetres then because I am using 1% of chemical admixture, I can reduce my water content from 180 to 160 which means that now my water cement ratio has gone down to 0.44 instead of 0.5.

Therefore, my strength will go up to greater than 32. So effectively I have used my chemical admixture to achieve higher strength. Now what else can we do? I can do this, i.e. I keep my water cement ratio the same. I am happy with the strength that I got so what I do is I am able to reduce this to 160 anyway so I keep this as 160. But I reduce my cement content also. So, I can do cement saving if I do not change the water cement ratio.

So, I can save the cement if I do not change my water cement ratio. You will notice that I am going with the simple and the old assumption that we had that slump is determined by the water content and strength is determined by the water cement ratio. The simplest perhaps too simple model which helps us understand how to use chemical admixtures which may or may not be necessarily very strictly true see for example if I use this, I have reduced my cement content so the amount of fine aggregate or the amount of coarse aggregate will change.

And therefore, it is not very proper to insist that my slump will be 8 centimetres. It might go a little bit here and there but the fact remains that the principle involved is that we can achieve cement saving. Because we are able to reduce the water proportionately, we can reduce the cement then if I do not change my water, I still keep it at 180 I keep my cement at 360 which means that I do not change this value and still I am using of course the chemical admixtures then I am getting slump which is greater than 8 centimetres.

And my strength will remain here because my water cement ratio is here and this is exactly what is the plasticizing action? So, I can get higher strength, I can get cement savings or I can get plasticizing action depending on how I change or alter the relative amounts of water and cement with respect to the base mix.

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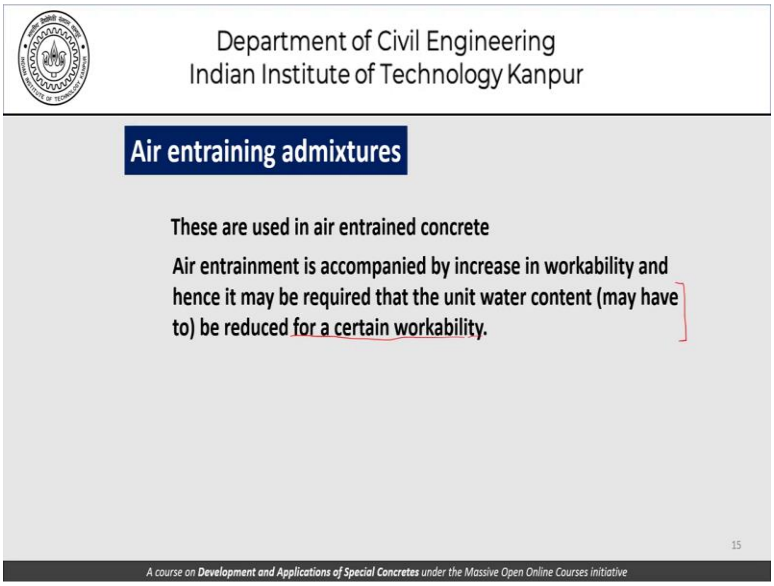

The third class of chemical admixtures is the air entraining admixtures now these are used to entrain air obviously. And air entrainment is accompanied by increase in workability and hence it may be required that the unit water content may have to be reduced for a certain workability. You will recall this principle when we did the adjustment in mixed proportions, we said that okay if we want to increase the air content by 1% the water content can be reduced by 3% and so on.

So, this is exactly what is being talked about here as the use of air entraining admixtures and air-entrained concrete is recommended for use in environments with cyclic freezing and thawing.

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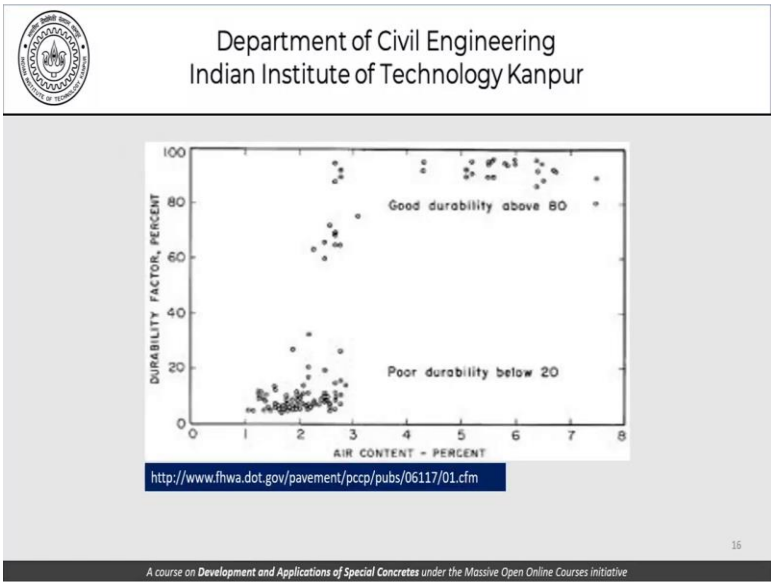

And we have seen this picture before in a slightly different form, if we do not have air content or we do not have air entrainment the durability factor is very low. But the moment the air content goes more than 3% or 4% the durability factor jumps to above 80 and that is what we want as far as the durability of concrete in freezing and thawing environments is concerned. And that is why we want to entrain air and we use air and drain concrete and for which you need air entraining admixtures.

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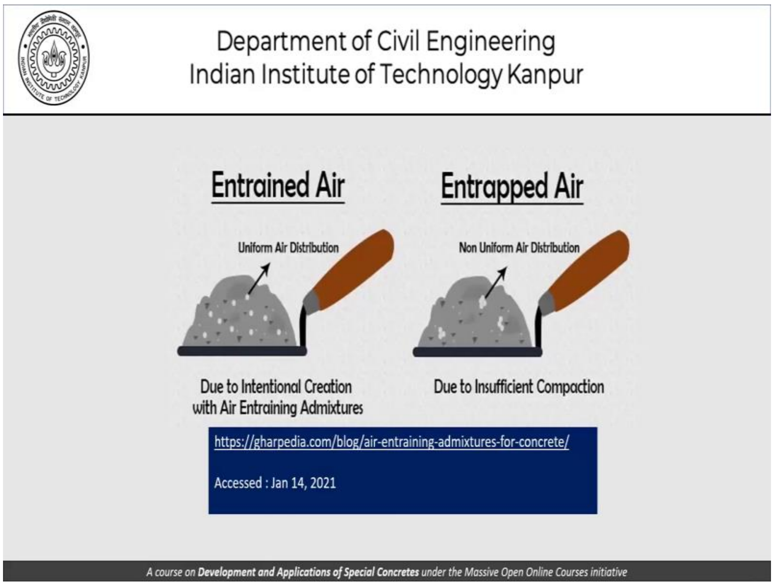

Now this is a schematic sketch of air entrainment, entrapped air is these large particles which are non-uniformly distributed and that is largely because of insufficient compaction. As far as entrained air is concerned it is a more uniform distribution of smaller sized air particles and this causes an increase in workability because of the ball bearing action.

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These are pictures taken from the research efforts of different people across the world showing entrapped air and entrained air within the concrete matrix.

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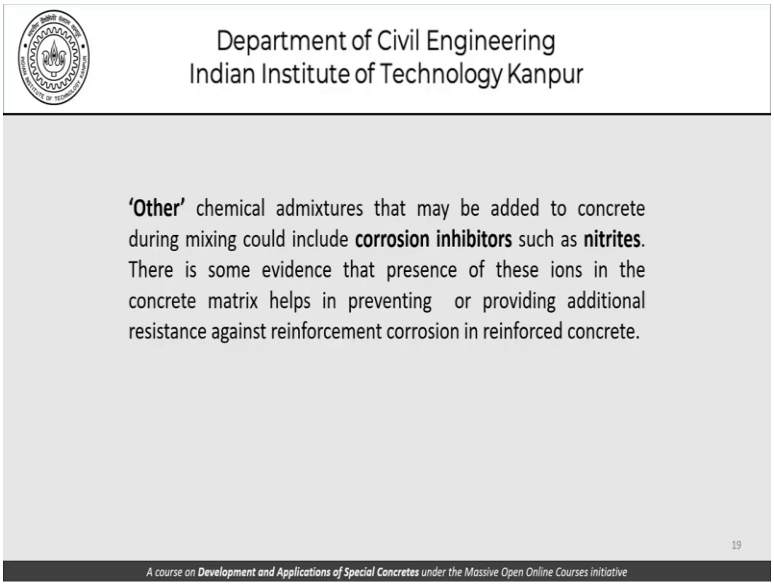

Other chemical admixtures that may be added to concrete during mixing could include corrosion inhibitors such as nitrites and there is some evidence that the presence of these ions in concrete matrix helps in preventing or providing an additional resistance against reinforcement corrosion in reinforced concrete. So, there are several types of chemical admixtures. What you need to remember is that these chemical admixtures are related.

Or they somehow try to interfere with the cement hydration and therefore the dosage is given in terms of the cement content and they are often dosed with water as an aqueous solution. So, these are some of the things that you need to just remember and use these chemical admixtures freely provided you understand the specifications, what you want out of it whether it is air entrainment or it is set regulation or it is water reduction.

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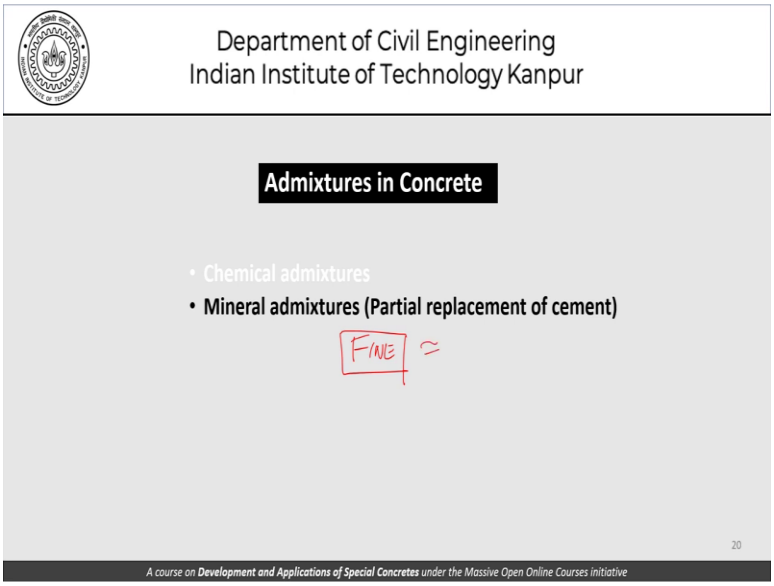

Having said that, let us go to mineral admixtures which are partial replacements of cement. Basically, these mineral admixtures are very fine now, that is something which we need to keep at the back of our mind all the time and their fineness to some extent has to be comparable to that of cement. In order that they are considered a part of the cement now, whether or not how much they take a part in the hydration reaction or how much they contribute to the hydration products is something that we will discuss.

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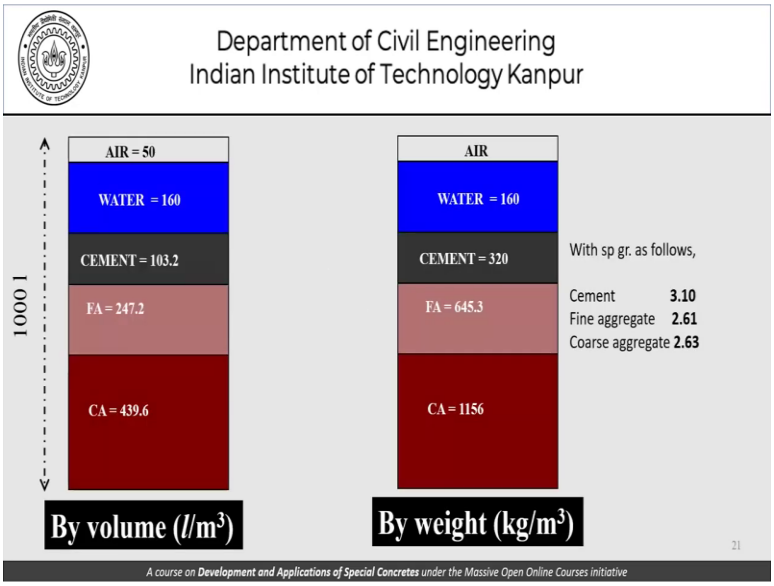

Now this is a picture again of normal concrete the same value is given here which is by volume and converted to weight. So, once we understand this volumetric distribution of the different components in normal concrete we have to understand or we have to think that if we add mineral admixtures to it, we have done that in an example that we did when we were doing proportioning of concrete mixes.

When we add mineral admixtures to it that also has to go into this 1000 litre pitcher the fixed volume of 1000 litres cannot be violated and therefore, we have to account for it when we are doing the volumetrics of the concrete. This we did not have to do when we were using chemical admixture. So that is a big difference between mineral admixtures and how they are handled within concrete proportioning and the chemical admixtures.

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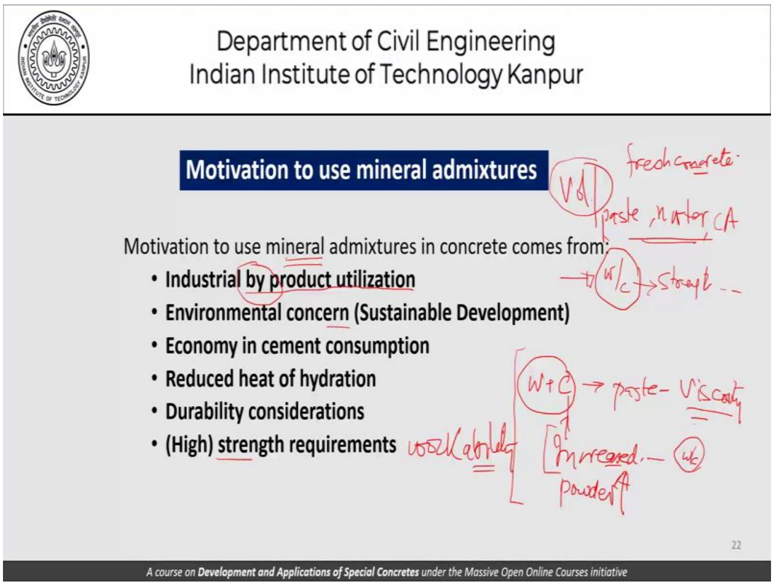

Now the motivation to use these mineral admixtures can be many; it could come from industrial by-product utilization. So, there could be some very fine in terms of fineness not necessarily they are good. But very fine industrial by-products like fly ash which the industry or the society or the profession does not know what to do and they are by-products they are not really the main products.

Nobody designed a factory to create fly ash but there is a lot of fly ash being produced in thermal plants, thermal power plants and we want to see whether it can find a place in the concrete. Environmental concerns there can be certain by-products, certain products from industries, there can be certain by-products which if left in the atmosphere or left in the environment could become difficult to handle and pose a hazard.

So, we try to see whether we can be localized within concrete. So, we try to see their potential as mineral admixtures in concrete. Economy in cement consumption, that is the corollary that happens or follows because if we use or we have a mineral admixture which can be used not only as a partial replacement of cement but also contributes to the strength development then we can obviously reduce the cement content and that leads to a lot of economy.

Reduced heat of hydration of cement durability considerations and high strength requirements. There are several dimensions which will prompt us to use mineral admixtures or to use products which will be classified or which can be classified as mineral admixtures in concrete not only the strength requirements but also workability requirements. We are going to talk about these issues more closely in greater detail when we talk about high strength concrete when we talk about self-compacting concrete.

As to what is really required, I am leaving it to you to think that if we had water and cement as the only constituents of a paste and it had a certain viscosity. Now how will this viscosity compare or what will happen to this viscosity if the cement content was increased? Do not look at this increase in cement from the point of your water cement ratio. Look at it from the point of view of increased powder content.

So, if we are able to increase the powder content, what happens to the viscosity or the change in viscosity upon increasing the powder content, that is the direction of thought. In fact, let me also tell you that when we are talking about the volume of paste, volume of mortar or volume of coarse aggregate these are properties which are very, very critical from the point of view of fresh concrete.

From the point of view of hardened concrete, one might argue that it is the water cement ratio that governs the strength and permeability and so on. And therefore, this is the only critical parameter. But as far as fresh properties are concerned or the properties of fresh concrete are concerned the volumes of powder, paste, mortar, coarse, aggregates all these things are very, very important. Try to mull over this thought and that will be very helpful in your understanding of special concretes.

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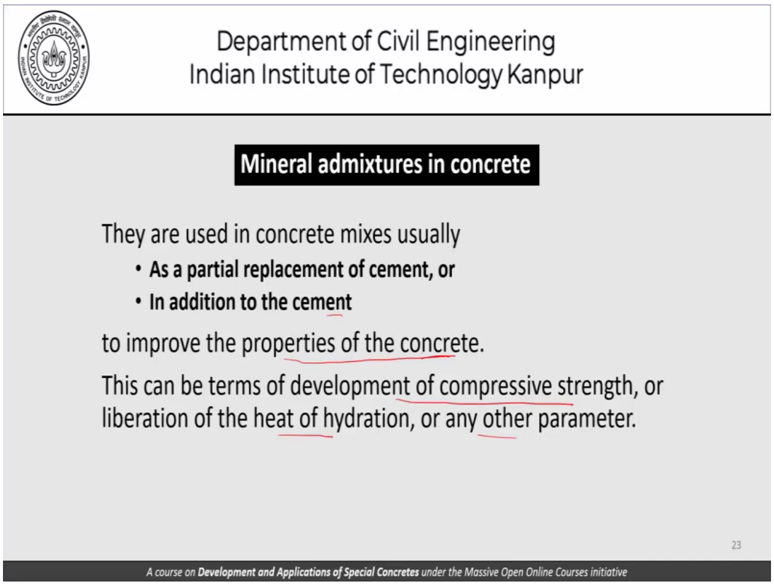

As far as mineral admixtures in concrete are concerned, if we start our discussion in earnest, they are used in concrete mixes usually as a partial replacement of cement or in addition to the cement to improve the properties of concrete. The idea is to improve the properties of concrete and for that we use mineral admixtures whether it is considered as part of the cement well and good even if not they are still used in addition to cement.

The properties of concrete that we talk about could be in terms of development of compressive strength or liberation of the heat of hydration or any other parameter that we can think of in terms of workability, permeability and so on.

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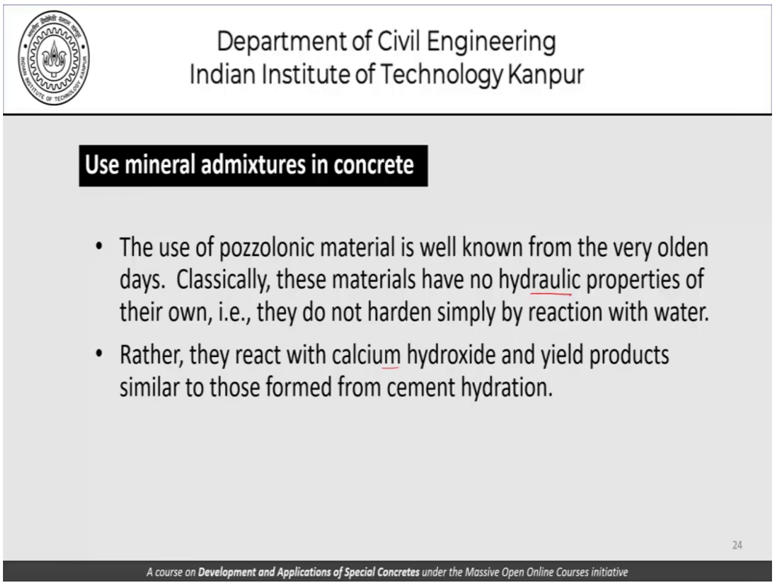

Using mineral admixtures has been of course known for a long time. And classically these materials have no hydraulic properties of their own. That is, they do not simply harden by reaction with water rather they react with the calcium hydroxide and yield products which are similar to those formed from cement hydration. And that is what we just see in one of the slides.

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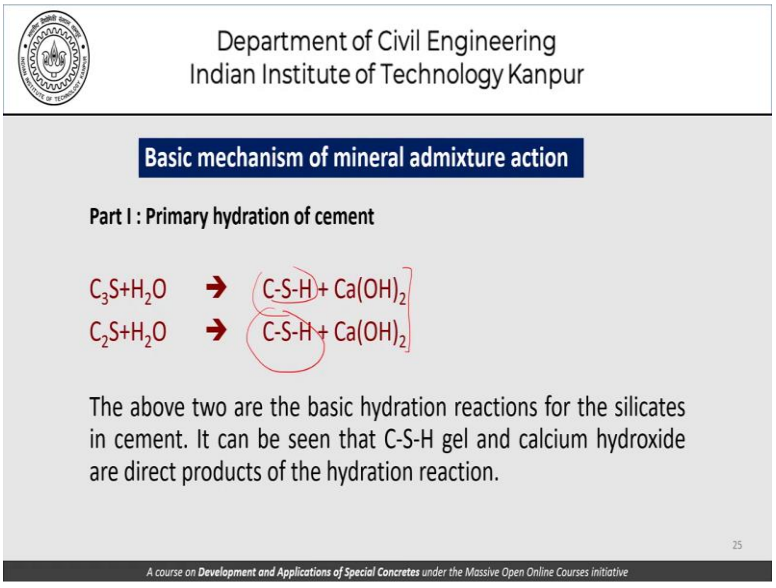

And the basic mechanism is initially there is primary hydration of cement that is C_2S, C_3S and so on, to give you a lot of CSH gel and calcium hydroxide in the usual manner. The above two are the basic hydration reactions for the silicates in cement and it can be seen that CSH gel and calcium hydroxide are the direct products of hydration.

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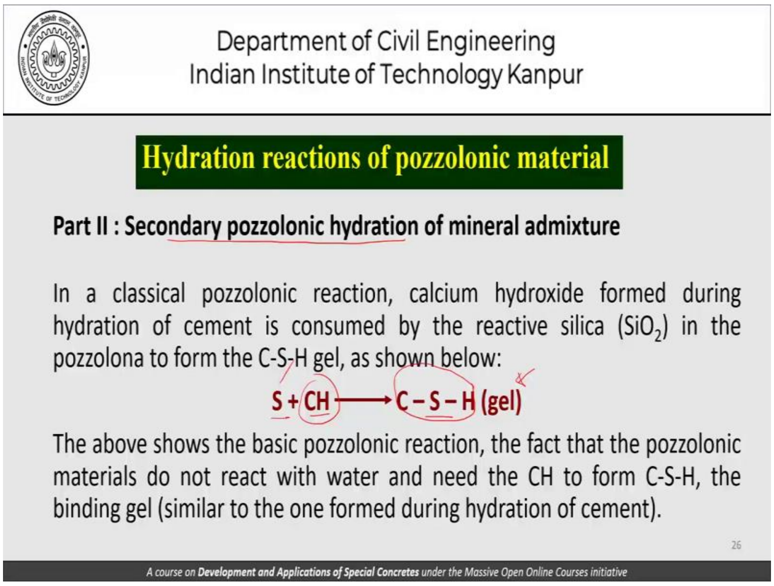

Then we go to the second step secondary pozzolanic hydration of mineral admixture. So, the secondary pozzolanic hydration is really at the root of the mineral admixture participating in the strength development or towards the strength. And in this classic pozzolanic reaction calcium hydroxide formed during the hydration of cement is consumed by the reactive silica in the pozzolan or the mineral mixture to form the CSH gel as shown here.

This silica here reacts to the calcium hydroxide to give you CSH gel and now this CSH gel was the original CSH gel that was formed in the primary reaction as well except that this additional CSH gel is now being formed when calcium hydroxide which was also formed during primary hydration reacts with the silica in the pozzolan material or the mineral admixture. So, this shows the basic mechanism of pozzolanic reactions or the mineral admixtures participation in terms of cement replacement.

Now if this does not happen or it happens to a lower level that takes us to the concept of the efficiency of the mineral admixture and also whether we can replace cement one to one or how much cement can be replaced by how much mineral.

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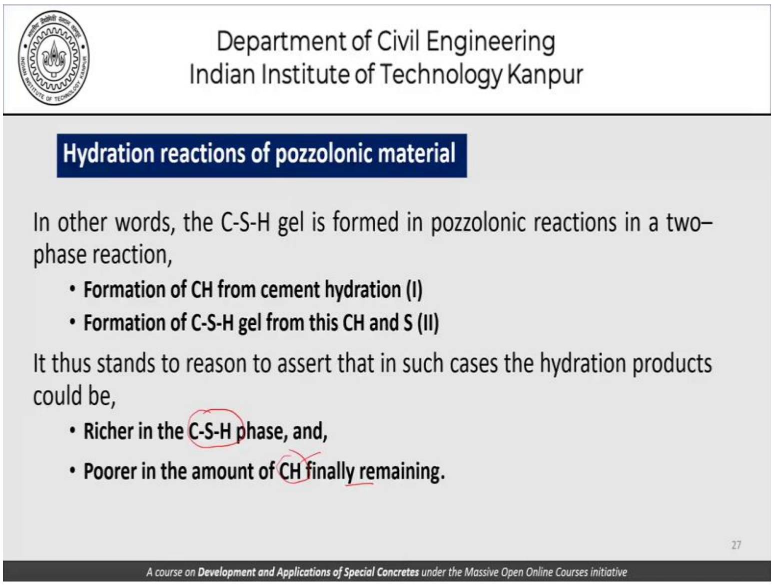

So as far as the hydration reactions of the poisoning material are concerned it is basically a two phase or a two-step process formation of calcium hydroxide from cement hydration and formation of the CSH gel from calcium hydroxide and silica. And thus, it stands to reason to assert that in such cases the hydration products could be richer in the CSH phase and poorer in the amount of calcium hydroxide that finally remains.

This calcium hydroxide is poorer because part of it gets consumed in the reaction with silica to form the additional CSH gel which is contributing to the richer part of CSH in cases when the concrete contains the mineral admixtures.

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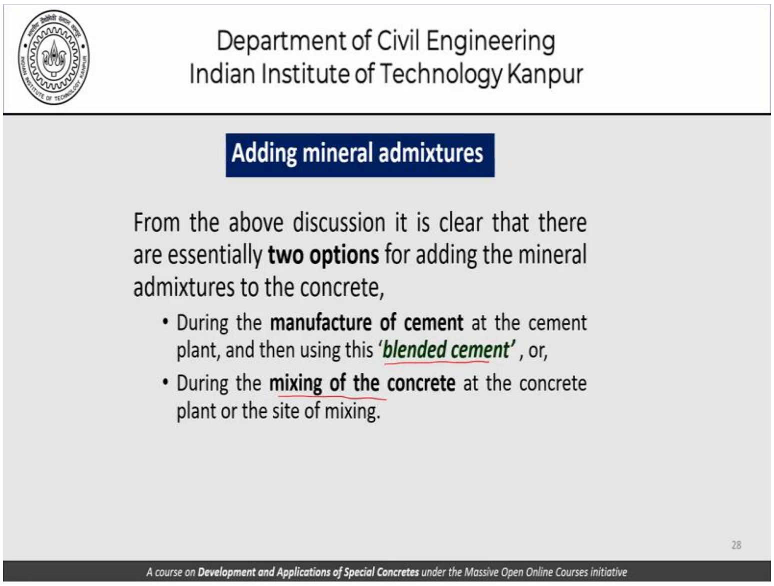

Now as far as adding mineral admixtures to concrete is concerned its two options; one is during the manufacture of cement and that is how we get blended cements or it could be used or it could be dosed at the time of mixing of the concrete at the batching plant. So, these are two ways of adding a mineral admixture to the concrete mix.

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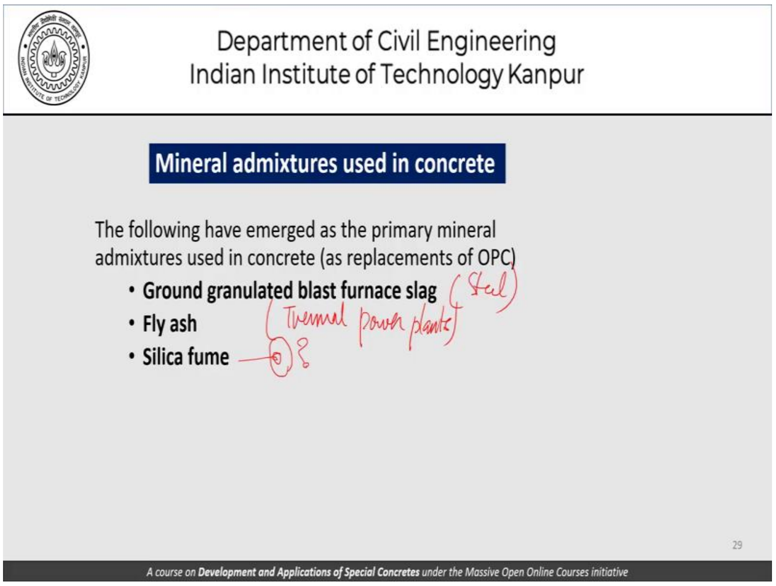

As far as the mineral admixtures used in concrete are concerned there are several of them most prominently the ground granulated blast furnace lag which is a by-product from the steel industry, fly ash which is a by-product from the thermal power plants primarily and silica fume there is something which I am leaving to you as an assignment as to where it comes from.

As far as the ground granulated blast furnace lag is concerned the characteristics of it the fly ash characteristics, silica film characteristics this is also being left to you as a homework, home assignment please try to take a look at available literature and understand a little bit about the properties of slag or fly ash or silica fume as it is used in the concrete as a mineral admixture. Other than these metakaolin, rice husk ash and so on are also available and are used.

Local material such as shiraz in Japan is also one of those admixtures which is known to have certain pozzolan properties and is used in concrete.

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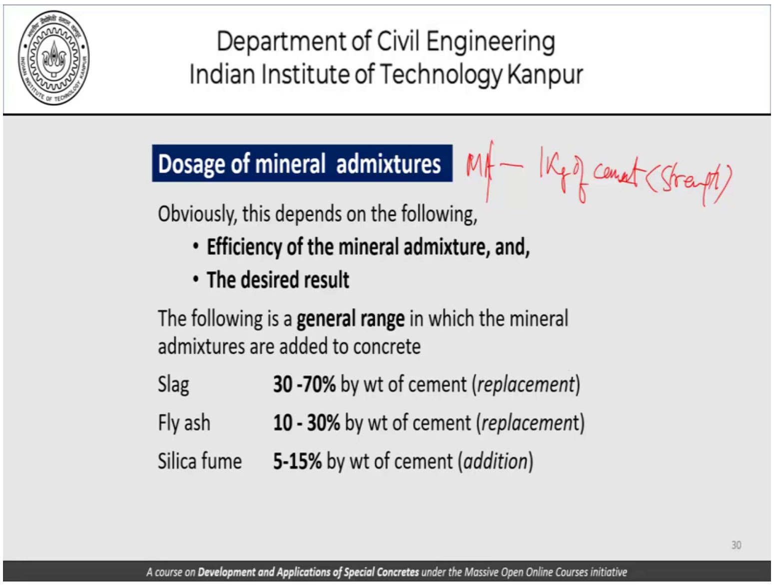

As far as dosing mineral admixtures is concerned it would depend upon the efficiency of the mineral admixture that is how much of the mineral admixture is needed to replace a kg of cement from the point of view of strength. So that would determine the efficiency of the mineral admixture and the desired result what do we want to get at the end of it. The following is a general range in which mineral admixtures are added to concrete, slag could be 30 to 70% by weight of cement, fly ash about 10 to 30% and silica fume is generally added only up to about 5 to 15% by weight of cement.

Now why these values are different is something we are not really going very deeply into at least at this point you can think about it maybe if time permits will come back and revisit this story. Having said that I would like to make a comment that the fact that slack can be used to replace as much as 70% of cement whereas fly ash normally is limited to 30% clearly shows that slag is a higher efficiency material compared to fly ash as far as mineral admixtures are concerned.

Think about it and you will come to your own conclusions. Another question which I want you to think about is why is the silica fume used restricted to about 5 to 15%. In fact, 15% is also one of the higher values most of the literature would probably show that use of silica fume beyond 10% is very, very rare. So, in fact silica fume is only added to about 5 to 7 and a half percent of cement. Why is this value so low? Think about it come to an answer and possibly will answer this question at some point in time.

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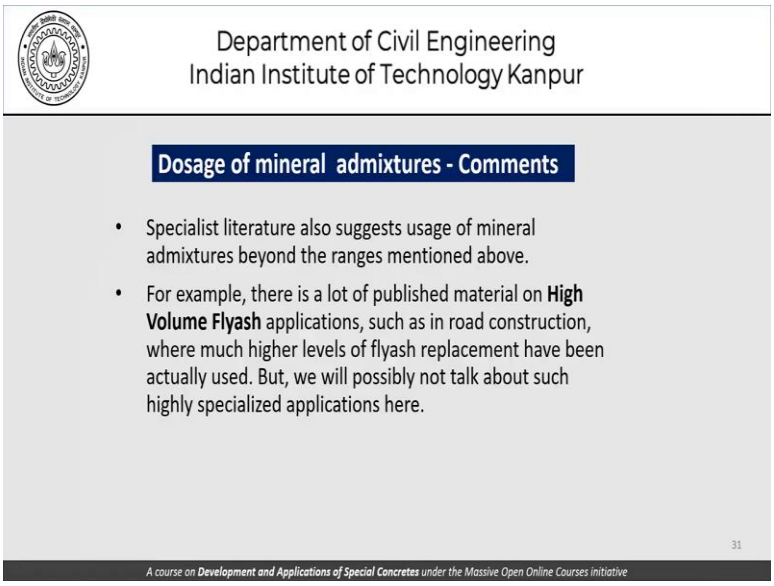

Some comments that I would like to make is that the specialized literature also suggests usage of mineral admixtures beyond the ranges mentioned above. For example, there is a lot of published material on high volume fly ash applications such as in road construction where the higher levels of fly ash replacement have been actually used. But we will possibly not talk about these kinds of more specialized applications at least right now. Maybe if time permits will spend some time on some of these special applications as well.

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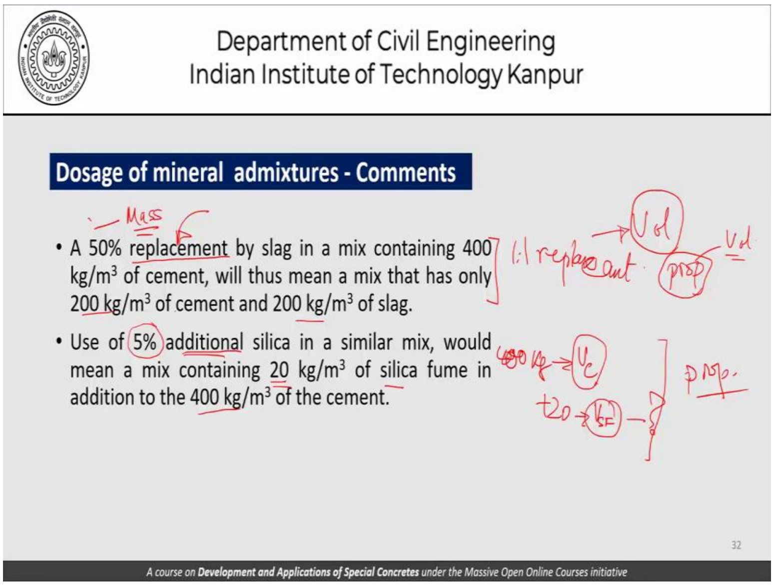

Now continuing our discussion on the dosage of mineral admixtures let us understand with the example what is replacement? A 50% replacement by slag in a mix containing 400 kgs of cement means that the mix will now have 200 kgs of cement and 200 kgs of slag this is a pure one is to one replacement. This obviously has implications on the volume because the volume of 200 kgs of cement will not be the same as the volume of 200 kgs of slag.

So, this is something which we have to understand and keep at the back of our mind when we are doing proportioning because our proportioning is basically a volumetric exercise this replacement is by mass. So, we have to have a very clear understanding in our mind as to what quantities are to be handled by mass and what quantities have to be handled by volume and how they are related.

So anyway, as far as replacement is concerned indeed this is the concept that if 50% replacement of cement means half the cement half of that mineral admixture. In addition to when we say that other than replacement there is an additional component. Suppose we say 5% additional silica fume is added then what we are saying is that the mix will now contain 400 kgs of cement as usual and 20 kgs of silica fumes will be added.

This again has volumetric implications because 400 kgs of cement as it is had a volume of cement in addition to that we add 20 kgs of silica fume and that will have a volume of silica fume and it will have to be adjusted somewhere. Now that adjustment will be done or needs to be done during the exercise of proportion that is what we have to keep in mind and we will see very shortly as to what that means.

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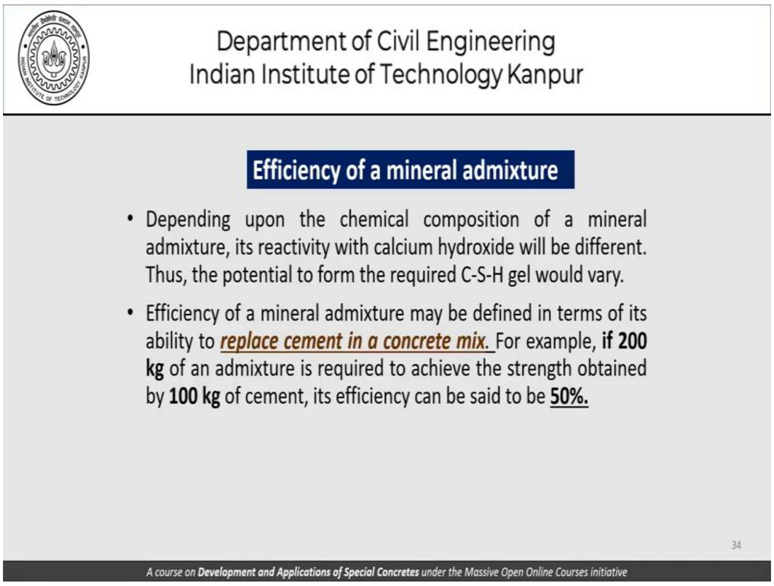

If we look at a schematic and an illustrative example let us say this is our base 350 kgs of cement per cubic meter that is the base no mineral admixture. Now here what we have done is 300 kgs of cement and 80 kgs of mineral admixture. So obviously what I have done is I have taken 50 kgs of cement out of the system and I have added 80 kgs of mineral admixture this is what I have done here.

In another case I have nothing I have not done anything to cement I have only added 80 kgs of mineral admixture. So, this here is replacement, this is addition and this replacement is not 1:1. what I showed you in the previous slide when I tried to replace 200 kgs of cement by 200 kgs of slag that was a 1:1 replacement by mass. Here it is not a 1:1 replacement here what I have done is 80 kgs of mineral at mixture is replacing 50 kgs of the cement and now we understand that possibly this concept of efficiency is coming into play.

And the mineral at mixture efficiency is about 60% that is we need 80 kgs of mineral admixture to replace 50 kgs of cement in order to have the same strength. In order to not compromise on strength if I remove 50 kgs of cement I need to put in 80 kgs of the mineral admixture. So, this is from the strength side that is in the hardened concrete.

But in the fresh state, the addition of mineral admixture has obvious implications on the paste and therefore the mortar content of the mix. Yet another spin-off or a corollary that arises out of all this discussion is, what is this concept of water to cement ratio when we are using mineral add mixtures. In normal concrete we know water we know cement but in a mineral admixture containing concrete or a concrete containing blended cements or in situations where the mineral admixture has been added in the batching plant what is the concept of cement?

Because it is not only the cement but also some part of the mineral admixture is also coming into play but not all of it see for example here. If we talk of the cementitious material component then it is 300+80. But if we think that the water cement ratio is W/380 that would be a misnomer because all this 80 is not taking part this part the denominator here is actually still 350. In fact, that is the whole idea that our strength is the same.

Strength being same means the water cement ratio is being preserved except that I am having to use 80 kgs here. So that is where this whole concept of water cement ratio becomes difficult to explain difficult to understand and difficult to standardize in cases where we are using mineral admixtures. Keep that the back of your mind when we deal with special concretes.

Now the efficiency of mineral admixture has already been talked about, depending upon the chemical composition of a mineral add mixture its reactivity with calcium hydroxide the efficiency will be different thus the potential to form the required calcium silicate hydrates would vary. The efficiency of mineral admixture may be defined in terms of its ability to replace cement in a concrete mix for example 200 kgs of an admixture is required to achieve this strength obtained by 100 kgs of cement its efficiency is 50%.

And the example that I showed you in the previous slides you can work it out and it will turn out that the efficiency is close to 60 to 62%.

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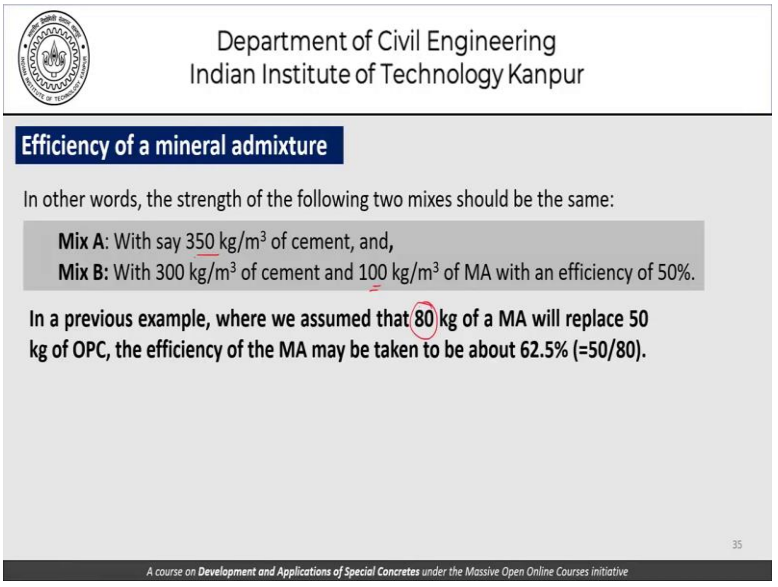

In other words, the strength of the following two mixes should be the same that is what I said 350, 300 plus 100 kgs of mineral add mixture with an efficiency of 50%. That is 50 kgs of cement has been replaced by 100 kgs of mineral add mixture. So, in a previous example where we had taken 80 kgs of the mineral admixture replacing 50 kgs of OPC or Ordinary Portland Cement or cement as we have been calling it the efficiency of the mineral admixture may be taken to be 62 if it was 50% instead of 80 kgs we will need 100 kg.

Now this picture has again been taken from a previous example where we did the proportioning using a mineral admixture with a certain efficiency and I am leaving it to you to revisit it from the point of view that now you should probably better appreciate the reason for keeping the coarse aggregate content fixed at 40%. Once I do this then what I am doing is I am only varying the relative proportions of cement mineral admixtures and fine aggregate together.

Because water content is something which I am not altering because of simplicity of course if I change these values the water demand will also change that something which I have not introduced at this point. What I can still do, what becomes clear from this discussion is that if we use mineral admixtures the paste content changes and if the paste content changes and we want to keep the motor content constant then the fine aggregate content needs to be adjusted.

If I do not do that then I have a problem at hand that the coarse aggregate will have to be reduced and that is the fine part of mixed proportioning. So that is something which we will probably see as we proportion and work with special concretes with special properties down the line as far as this discussion is concerned.

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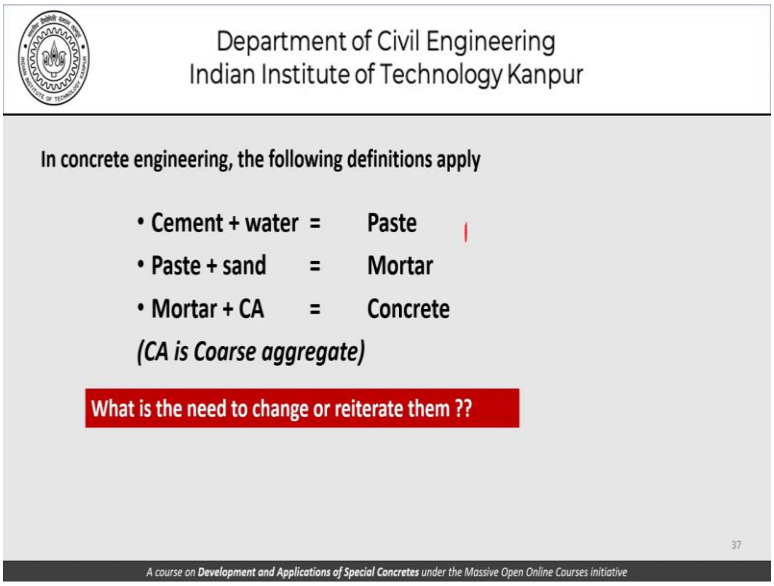

We have reiterated cement plus water is based paste plus sand is mortar, mortar plus coarse aggregate is concrete. The need to change or reiterate them arises from the fact that where does mineral admixture fit in as far as this discussion is concerned. The mineral admixture being of the same fineness as cement typically would become a part of the paste phase that is something which you need to remember and that is why you need to characterize mineral admixtures among other things.

For fineness to determine whether or not you would like to treat them as a part of cement not only from the strength development and pozzolan reaction point of view but also from their contribution in terms of modifying the properties of water in order to get paste which will of course determine the properties of mortar and finally the properties of concrete in terms of workability most of the time.

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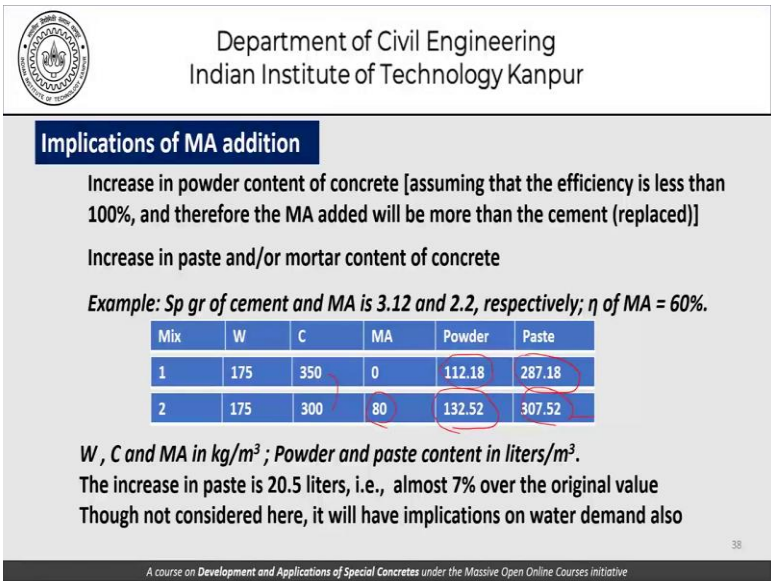

Having said that the implications of mineral admixture addition is that increase in powder contents of concrete assuming that the efficiency is less than one and therefore the mineral admixture added will be more than that of the cement replaced that is by mass increase in the paste and or the mortar content of concrete. And that we have already seen that if we have something like this 175 kgs of water 350 kgs of cement 50% water cement ratio no mineral admixture.

We are looking at 112 litres or 11.2% of the thing being powder about 28%, 29% being paste. Whereas if we use 80 kgs of mineral mixture to replace 50 kgs of cement and my paste content goes up by 20 litres as well. And these 20 litres are quite a substantial change given the fact that the original was only 287. So, this W, C and mineral admixtures as in kgs per cubic meter powder and paste content is in litres per cubic meter.

The increase in paste of 20.5 litres is almost 7% over the original value though not considered here it will have implications in water demand as well. I already told you that the surface area of 300 kgs of cement and 80 kgs of mineral add mixtures will not be the same as the surface area of 350 kgs of cement. And therefore, to insist that the workability will be the same at 175 kgs of water or for that workability we still need 175 kgs of water is a little bit of an exaggeration but from the point of view of argument I will still stick to it.

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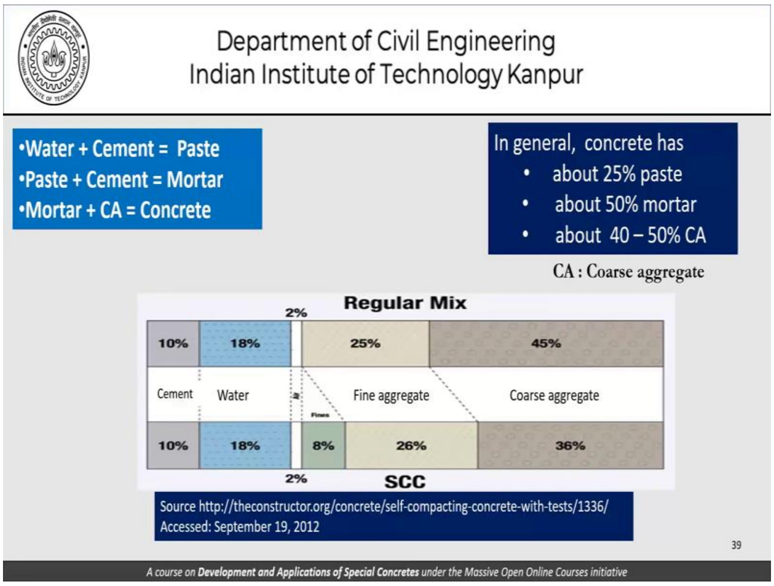

This picture here shows the distribution of some of these materials and here we have self-compacting concrete we talk about it in greater detail later on 45% is the coarse aggregate content in normal concretes which is only about 35-36 in self-compacting concrete. Which means that the mortar content is more now if you look at different self-compacting concretes you will realize that the fine aggregate content is not really very different it is 25, 26% in both cases which means that the paste content is high.

Now the paste content is higher means either we push the cement content higher or we increase some kind of a fine material because if we keep increasing the cement, we run into other difficulties in terms of the heat of hydration shrinkage and so on. Therefore, we would like to keep the cement low but use some fine material which will increase my paste content which will increase my mortar content and that is what is a very important contributor to the self-compactability of a concrete mix?

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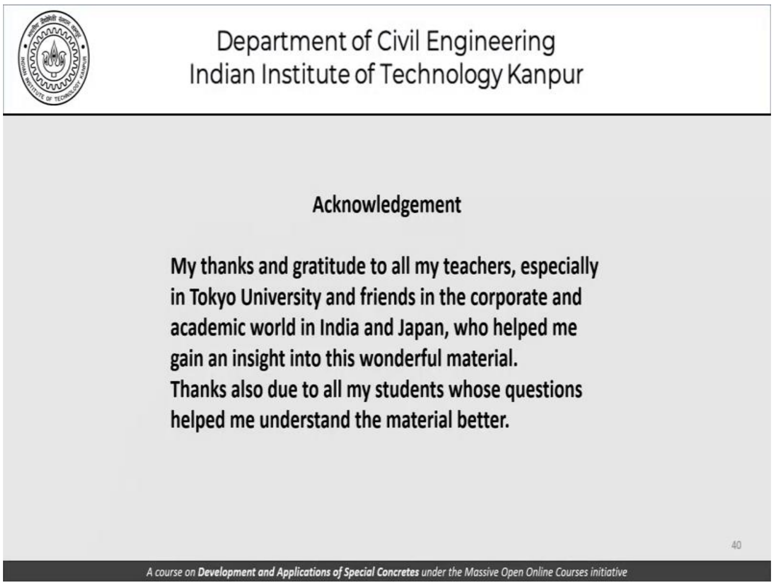

Once again, I thank my teachers my students and my friends who have contributed to my understanding of concrete. And thank you once again for being patient and going through this lecture. I look forward to seeing you again in the next lecture as well as keeping you company in this journey of development and applications of special concretes, Thank you.